X-ray Spectroscopy of Cataclysmic Variables from *Chandra* HETG to *Astro-E2* XRS

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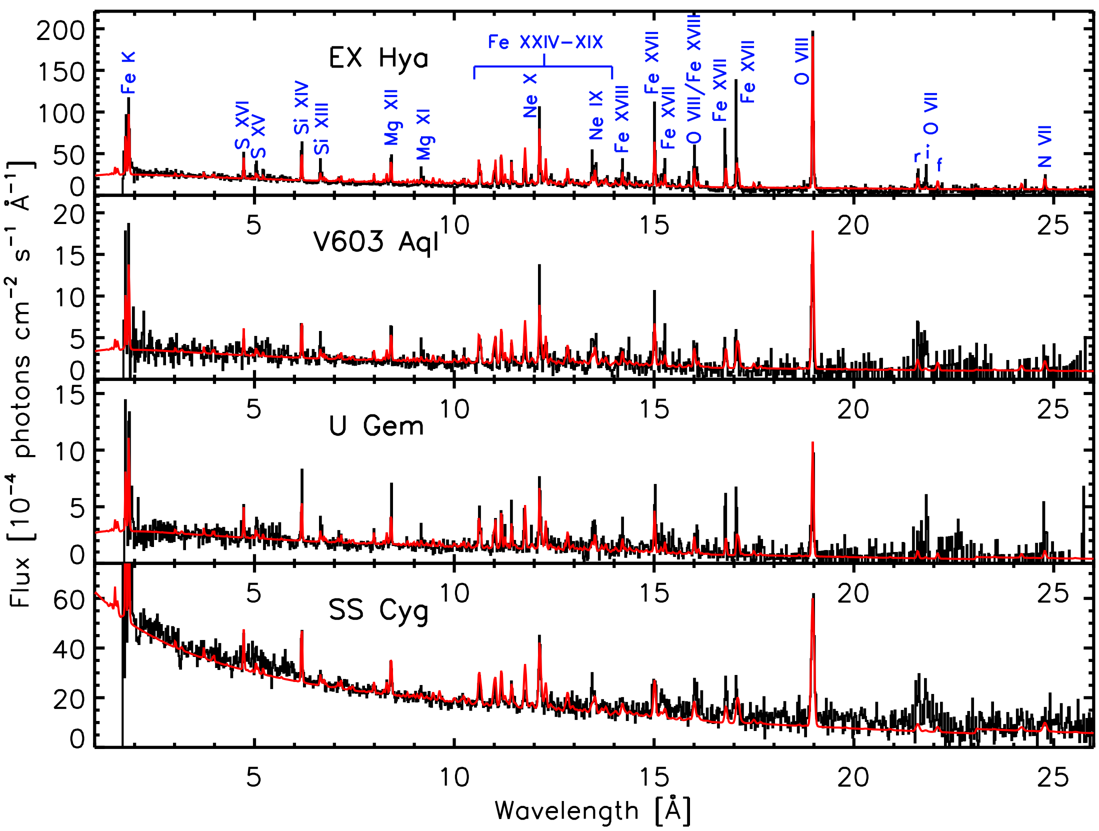
Mukai, Kinkhabwala, Peterson, Kahn & Paerels (2003, ApJLett 586, L77) found that *Chandra* HETG spectra of cataclysmic variables can be divided into two distinct types.

Cooling Flow CVs



Advection-Dominated Region

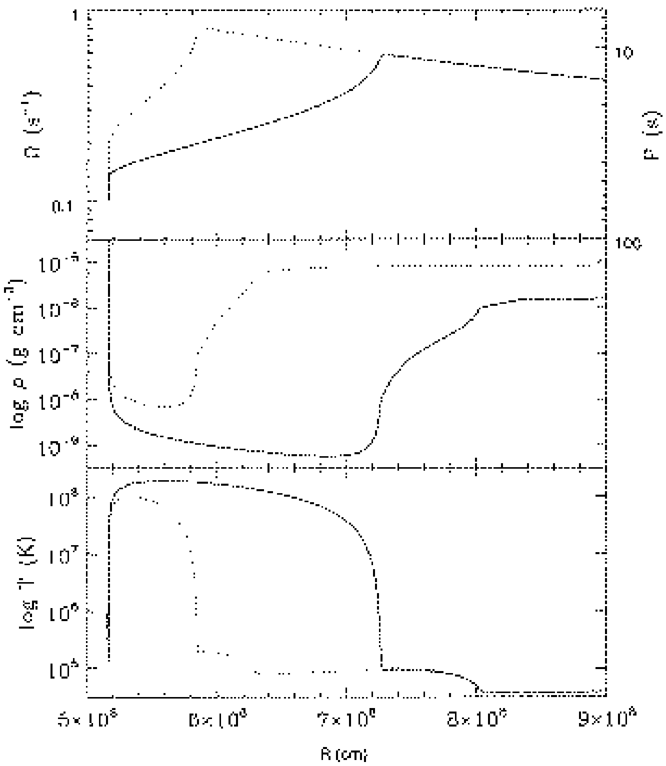
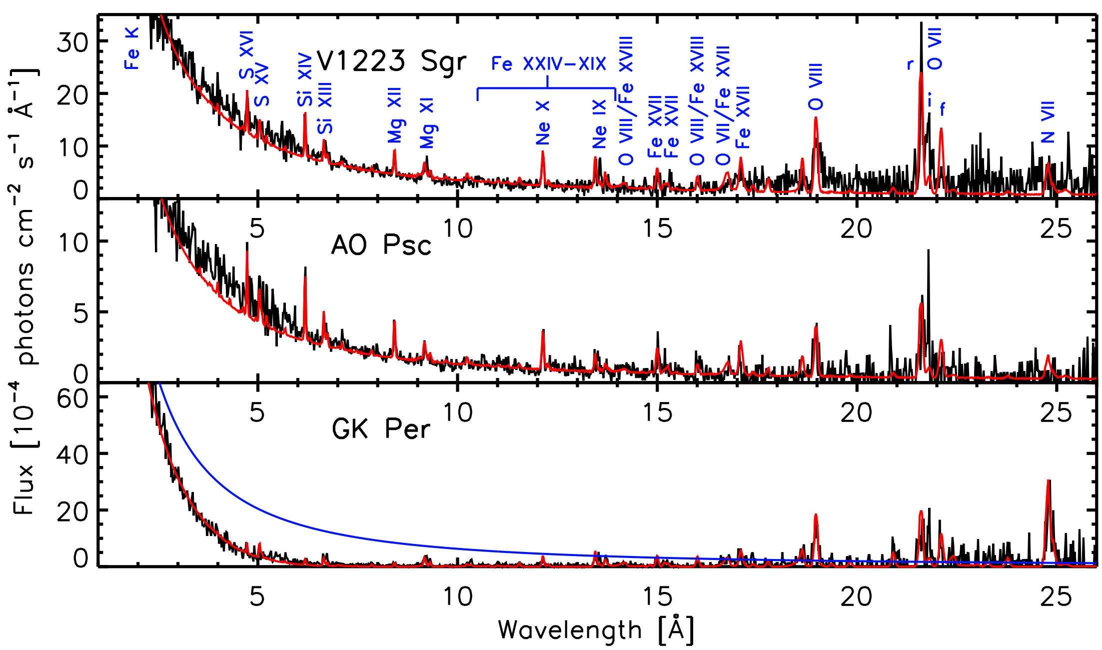


Figure 1 of Popham (1999, MNRAS 308, 979), showing boundary layer solutions from Narayan & Popham (1993, Nature 362, 820) for $10^{-9.5}$ $M_\odot$ yr^{-1} (dashed) and $10^{-10.5}$ $M_\odot$ yr^{-1} (solid).

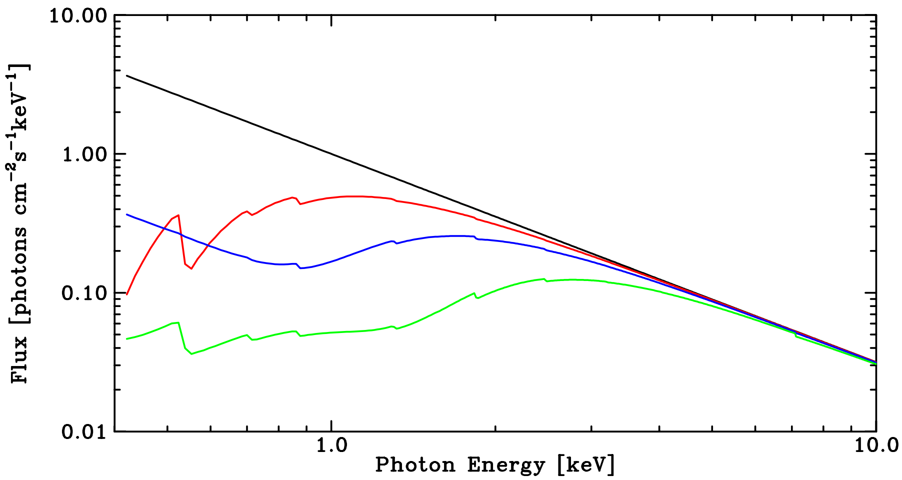
The Cooling Flow emission comes from the extreme left of this graph where lines are vertical. There is a much larger region which is hot but radiatively inefficient, adding a small amount of high temperature emission.

Photoionized CVs



What is the origin of the hard, power-law like continuum in these CVs?

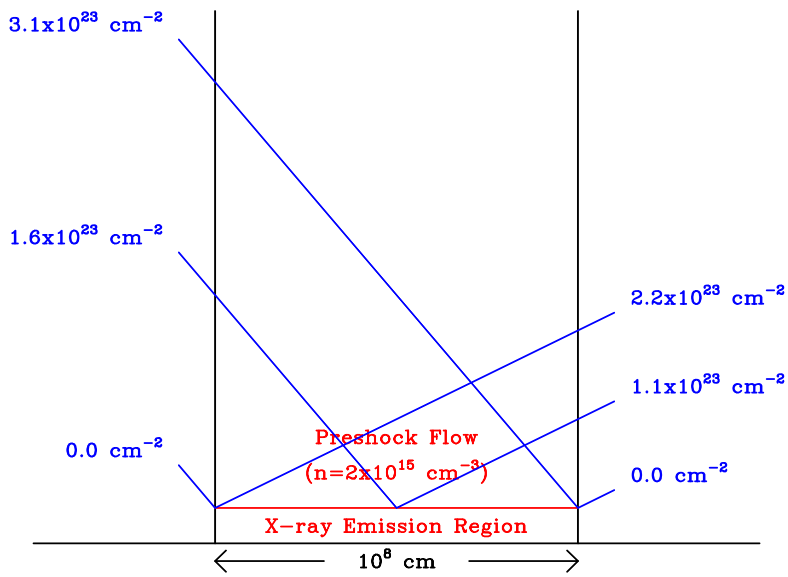
Intrinsic Absorption



A simple absorption (red) will not create a hard power-law from bremsstrahlung continuum.

Partial covering fraction models (1 ore 2 components) are adequate for CCD-resolution spectra, but do not appear to work for *Chandra* HETG data.

Geometry of Absorption in the Pre-Shock Flow



In reality, we expect a continuous distribution of N_H from 0 to a very high value in magnetic CVs. What would result from a continuous, rather than discrete, distribution of absorbers?

Analytical Approximation

Done & Magdziarz (1998, MNRAS 298, 737) considered a power-law distribution of covering fraction with column $C_f(N_H) \propto N_H^{\beta}$. Their equation (1) reads:

$$S(E) = S_{\rm int}(E) A \int_{N_{H,min}}^{N_{H,max}} N_H^{\beta} \exp\left(-N_H \sigma(E)\right) dN_H \tag{1}$$

This has been implemented numerically as xspec model, pwab. Analytically, we obtain, using $u = N_H \sigma(E)$:

$$T(E) \propto \sigma(E)^{-\beta-1} \int_{u_{min}}^{u_{max}} u^{\beta} \exp\left(-u\right) du \tag{2}$$

for the transmission $T(E)$. The integral can be expressed in terms of incomplete gamma function $P(a,x) = 1/\Gamma(a) \int_0^x t^{a-1} \exp\left(-t\right) dt$ so that

$$T(E) \propto \sigma(E)^{-\beta-1} [P(\beta+1, u_{max}) - P(\beta+1, u_{min})] \tag{3}$$

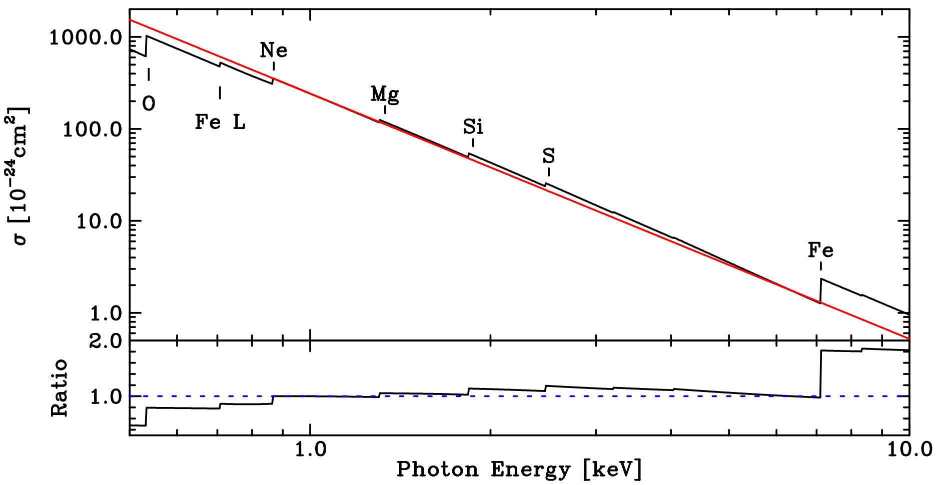
If $N_{H,min}$ is sufficiently small and $N_{H,max}$ is sufficiently large, there is a range of E such that $P(\beta+1, u_{max}) \sim 1$ and $P(\beta+1, u_{min}) \sim 0$, so that

$$T(E) \propto \sigma(E)^{-\beta-1} \tag{4}$$

At the same time, $\sigma(E)$ itself can be approximated by a power law of E. For example,

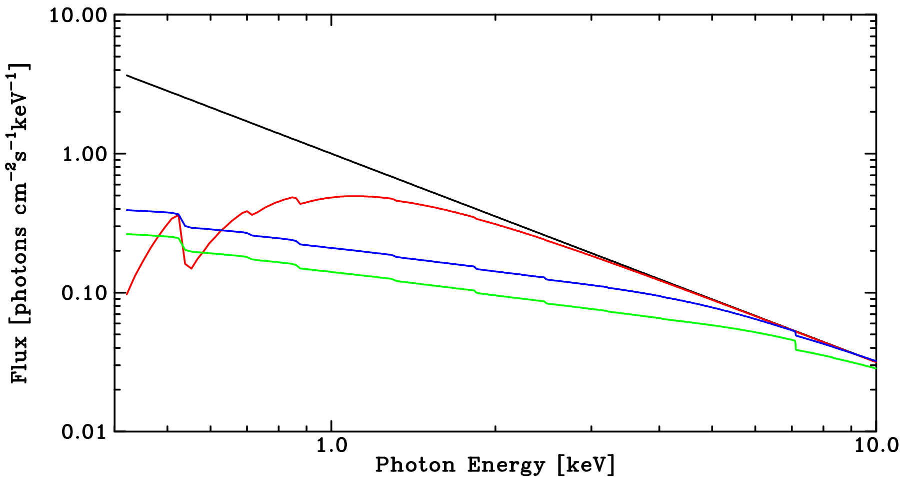
$$\sigma(E) = 2.242 \times 10^{-22} (E/1keV)^{-8/3} cm^{-2} \tag{5}$$

is a good approximation of the Morrison & McCammon cross section.



Thus, $T(E)$ can be approximated as a power-law of E between O and Fe edges.

Power-law Cut-off



Numerical integration using pwab model in xspec are shown on left. They do indeed result in a power-law, rather than exponential, cut-off.

In this particular simulations, two different values of $N_{H,max}$ were used with the same β. Note that there is no hardness modulation below ~5 keV. Both the Fe K and O K edges are prominent; however, the former is not strong enough to be detected in *Chandra* HETG data.

Prospects for *Astro-E2* observations

For pure Cooling Flow systems, *Astro-E2* observations will:

- Measure the densities using He-like triplets of Si, S, and Fe.
- Measure the departure from a pure Cooling Flow, allowing inferences to be made on the advection-dominated region.

For Photoionized systems, *Astro-E2* observations will:

- Test if the underlying the continuum is due to Cooling Flow emission.
  - Confront the prediction of power-law like absorption.
  - Detect Fe K and O K edges exist simultaneously, perhaps also weaker edges of intermediate elements.
- Measure the ionization structure of the complex absorber.
- Measure the parameters of the Cooling Flow.

In general, we cannot rely on exponential cut-off to identify intrinsic absorption (and in the total spectrum of an ensemble of variously absorbed sources, such as the Cosmic X-ray Background).